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EFFECT OF IRRIGATION RUN-OFF ON SURFACE WATER SUPPLIES

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GRAND RAPIDS, MICHIGAN
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EFFECT OF IRRIGATION RUNOFF ON SURFACE WATER SUPPLIES

By

Paul D. Haney[1] and Thomas W. Bendixen[2]

Irrigation Water Use

Our interest in irrigation stems from the facts that (a) irrigation agriculture is the Nation's largest user of fresh water resources and (b) drainage from irrigated areas may have important effects on water quality. This discussion is concerned mainly with chemical water quality changes associated with irrigation use.

There are now approximately 26 million acres of irrigated land in the United States. The bulk of this land is located in the 17 states west of the 95th meridian. These 17 states comprise about 60% of the area of the nation (1). Agriculture throughout much of this vast region must be supported by irrigation. In 1890 there were only about 4 million acres of western land under irrigation (2) but this acreage more than quadrupled during the next 30 years. Since 1920, acreage under irrigation has increased at a much slower rate. Future growth will be determined by the availability of water at a price commensurate with the benefits derived from its use for irrigation.

Only about 1.5 million acres (3) are now under irrigation in the eastern states. A certain amount of irrigation in the humid eastern areas is advan-

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tageous because crop failures can be prevented during dry years and higher yields can be obtained during normal years. The outlook is for increased use of water for irrigation in the east (2).

For the entire nation irrigation leads all other water uses by a considerable margin. Sources and estimated use of fresh water in the United States in 1950 (4) (5) are shown in the following table:

TABLE 1
SOURCE AND USE OF FRESH WATER IN THE U.S. (1950)
BILLION GALLONS PER DAY

	From Wells	From Streams and Lakes	Total	% of Total
Rural	2.8	0.7	3.5	2
Municipal	3.5	10.0	13.5	8
Industrial	6.	59.	65.	38.
Irrigation	18.	70.	88.	52.
Total (rounded)	30.	140.	170.	100.

Total water resources use has roughly quadrupled within the past 50 years (4).

The following table indicates the approximate extent of water use for various purposes in the eastern and western regions of the United States (4).

TABLE 2
APPROXIMATE REGIONAL WATER USE (1950)

	17 Western States	31 Eastern States
Total Withdrawal	95. Billion Gal. Daily	75. Billion Gal. Daily
	% Total Western Use	% Total Eastern Use
Domestic Users	5.	16.
Private Industries	3.	81.
Irrigation	92.	3.
	100	100

This indicates a present irrigation use in the West of the order of 90 billion gallons daily. One estimate (4) places the amount for irrigation in 1975 at about 110 billion gallons daily.

Consumptive Use of Water

Of the total water withdrawn for rural, municipal, industrial and irrigation use, probably about 60% is returned to the natural drainage and is available for re-use. The bulk of this return is from industries and municipalities.

A substantial portion of the water used for irrigation is consumed by evaporation and transpiration. Applied to irrigation agriculture, the terms "evapotranspiration" and "consumptive use" have received general acceptance. These terms have been defined as "the quantity of water transpired by plants during their growth or retained in the plant tissue plus the moisture evaporated from the surface of the soil and the vegetation expressed in feet or inches depth of water lost or used in a specified time" (6) (7). Consumptive use accounts for roughly two-thirds of all the irrigation water used. The irrigation water not accounted for by consumptive use generally finds its way back to the stream channel from which it was diverted. This is frequently referred to as "return flow." Part of this return flow reaches its stream through surface runoff and part as underground seepage. Of the total water used for irrigation, probably no more than about one-third is available as return flow for re-use for irrigation or other purposes.

Estimated consumptive water use (4) as of 1950, on a regional basis, is shown in the following table.

TABLE 3

ESTIMATED TOTAL AND CONSUMPTIVE WATER USE (1950)

	Total Use in Billion Gallons per Day		Per Capita Use in Gallons per Day	
	17 Western States	31 Eastern States	17 Western States	31 Eastern States
Fresh water withdrawal	95	75	2700	650
Consumptive use	60	7	1700	60
Population in millions	34.4	117.4		

The amount of water withdrawn for irrigation varies widely. Diversions for irrigation range from less than 2 to more than 10 acre-feet per acre per year (2). Not all of this water is available for crop production for there is a significant loss in getting it to the fields. Part of this loss is due to seepage from the conveyance ditches and canals. Some loss results from evaporation from water surfaces and transpiration by weed growths along the ditches. From 20 to 60% of the water diverted may reappear as return flow. A general average value for return flow is about 33% (3) (4).

Salt Balance

Maintenance of a favorable salt balance is an important aspect of irrigation practice. According to Houk (2) the salt balance of an irrigated area may be defined as the difference between the total dissolved solids brought to the land annually by the irrigation water and the total solids carried away annually by the drainage water. When the input of mineral salts is less than the output the salt balance is favorable. When the input is the greater the salt balance is unfavorable. If the salt input is definitely less than the

output, undesirable salts do not accumulate in the root zones, but when the input is significantly greater than the output, undesirable salts probably do accumulate around the roots. Conditions within the root zones determine the agricultural suitability of the land (2).

The object of irrigation project drainage is not only to remove surplus water but also to remove from the irrigated area approximately as much harmful mineral matter as is brought in by the water applied to the land (8).

Some studies (9) indicate that at least ten per cent of the water added to the soil should go on through as drainage water to leach salts. This value must be increased as the quality of the irrigation water decreases and as the clay content of the soil increases, in order to control the salt balance.

Tests at the Rubidoux, California, laboratory of the Department of Agriculture were made on the growth of alfalfa. Irrigation water containing a rather high total salt concentration (about 1000 ppm) was applied to the alfalfa and the percolate measured and analyzed. The conclusions of this study, as given by Houk (2) were:

(1) It was necessary to use 22.5% of the input water for leaching in order to prevent accumulation of salts in the root zones.

(2) The alfalfa and soil absorbed about 14% of the salts in the irrigation water.

(3) About 800 pounds of water were evaporated and transpired for each pound of dry alfalfa produced.

Illustrations of the trend of salt balance conditions for three irrigated valleys have been reported by Scofield (10). Two of the areas are along the Rio Grande in the vicinity of El Paso, Texas, and the third along the Colorado River near Yuma, Arizona. In each case the volume and salt constituents

of input as irrigation water and output as drainage water were measured. A portion of Scofield's data is shown in the following table.

Table 4 - Salt Balance in Some Irrigated Valleys

Condition	Mesilla Valley (New Mexico-Texas)	El Paso Valley (Texas)	Yuma Valley (Arizona)
Irrigated area, acres	80,000	60,000	40,000
Irrigation water, acre-feet	744,380	496,113	259,917
Drainage water, acre-feet	496,113	173,219	57,095
Per cent of irrigation water	66.6	34.9	22.0
Salts in irrigation water, tons/acre-ft	0.805	1.226	0.956
(ppm)	(592)*	(900)*	(704)*
Salts in drainage water tons/acre-ft	1.226	2.666	1.993
(ppm)	(900)*	(1970)*	(1470)*
Output of salts per cent of input, tons	101.5	75.9	45.8
Output of salt constituents per cent of input, concentration	152	218	208

* Not given in original table.

The data presented show the trend of salt-balance conditions for each area in respect to the total salts. With respect to total salts, only the Mesilla Valley had a favorable salt balance. Certain salts were accumulating in the soils of the other two valleys, which had unfavorable salt balances. However, in all cases the concentration of salts in the output waters was increased by 50 per cent or more.

Water Quality Data

Repetition of the process of withdrawal for irrigation use, evapotranspiration and return to the natural drainage of a portion of the water can result in a gradually increasing concentration of dissolved mineral matter in the streams receiving drainage from irrigated land. Streams generally show a progressive increase in dissolved mineral concentration between headwaters and mouth (11). However, diversion of water for irrigation use, followed by return of only a portion containing much of the water's original mineral load plus additional salts leached from the soil, may markedly increase this natural trend. This was noted over 50 years ago by Headden (12), who studied the Cache La Poudre and other streams in Colorado.

The Cache La Poudre River rises in the mountains of northern Colorado and flows generally southeastward, joining the South Platte River near Greeley, Colorado. It has a drainage area of about 1840 square miles. Approximately 1050 square miles of drainage area are tributary to the Ft.Collins gage, located about 50 miles from the mouth of the Poudre. The average annual discharge at this point is 409 cfs (13). At the gage located 2.5 miles from the mouth, the average annual discharge is only 93.4 cfs (13). This large decrease in annual discharge with increase in catchment area indicates the extensive consumptive use of the waters of the Poudre. There were about one quarter million

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acres of land under irrigation in the Poudre watershed in 1944. Irrigation water use in 1944 was reported to be 332,900 acre-feet. The length of the main stem is approximately 120 miles. Major main stem irrigation diversions begin at a point about 50 miles from the mouth of the Poudre (14).

Clarke (11), referring to Headden's (12) earlier work, describes the changes in the Poudre River as follows:

"The Cache La Poudre River in Colorado flows first through a rocky canyon over boulders of schist and granite and thence emerges upon the Plains. Its waters are then diverted into ditches and reservoirs for purposes of irrigation and finally reach the Platte near Greeley. In performing the work of irrigation they acquire a new load of solid matter and the progressive changes in their composition are clearly shown by Headden's analyses."

Headden's analyses (12) published in 1903 showed a large increase in dissolved solids in a 50-mile reach. At a point about 55 miles from the mouth, the stream had a total dissolved solids content of 37 ppm. At a point 2 miles above Greeley, Colorado, which is about 7 miles from the mouth, the solids content had increased to 1571 ppm.

Data on quality changes computed from Clarke's report (11) of Headden's (12) analyses are presented in the following table:

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TABLE 5

QUALITY CHANGES, CACHE LA POUDRE RIVER, 1902

Approximate miles from mouth	55	9
Approximate flow, cfs	Not given*	24**
Date of sample collection	11/3/02	8/11/02
Total hardness, ppm	18	920
Alkalinity as $CaCO_3$, ppm	20	190
Noncarbonate hardness, ppm	0	730
Sulfate as SO_4^{--}, ppm	3.4	940
Chloride as Cl^-, ppm	1.5	40
Total dissolved solids, ppm	37	1571

*Sample "was taken at a time when there was no flood water and after a period of good weather ... the water then flowing represented the normal water of the Poudre ..." Headden (12).

**Flow on July 27, 1902, at or near sampling station. Headden (12).

It is apparent from these data that the waters of the Poudre gained a considerable load of solid matter and that the percentage composition of the dissolved mineral matter was altered to a marked extent. Clarke (11) indicated that this change was due in part to the use of the water for irrigating an originally arid soil containing much soluble matter and that thorough leaching probably would result in less exaggerated changes. Irrigation started in the Poudre valley long before 1902 and has been actively practiced ever since. Limited data comparable to the 1902 data were collected in connection with a water pollution survey (14) on the Poudre during 1948 and 1949.

These data show that changes in quality of the order found by Headden in 1902 persisted nearly a half century later. Some results from the 1948-49 survey are shown in the following table:

Table 6

Water Quality Changes, Cache La Poudre River

1949 Data (14)

Approximate miles from mouth	50		14	
Flow, cfs	32	32	45	45
Date of sample collection	6/15/49	6/20/49	8/26/49	9/13/49
Total hardness, ppm	25	17	816	918
Total alkalinity as $CaCO_3$, ppm	28	22	258	286
Noncarbonate hardness, ppm	0	0	558	632

Similar changes were noted in the quality of the South Platte River, which receives irrigation return flow from about 1.25 million acres (14).

Banks and Lawrence (15) have discussed the influence of irrigation drainage on water quality in the San Joaquin River in California. They define "degradation" as "an impairment to quality caused by the development, use and re-use of the water itself" and cite one cause of such impairment as the inflow of irrigation drainage. Such drainage water, they state, may contain 4000 ppm or more of total dissolved solids and can cause a marked change in composition of the receiving waters, generally an increase in the proportion of sodium salt salinity. Total solids in the San Joaquin River were increased more than 15-fold in a river reach of 85 miles (34 ppm to 570 ppm). There was a more than 40-fold increase in chloride in this same reach (3.8 ppm to 170 ppm).

Therne's (9) investigation of the Sevier River in Utah showed progressive mineralization occurring in this stream due mainly to irrigation return flow. Increasing mineralization is said to create an irrigation water quality problem in the lower portion of the Sevier River drainage area (9).

Data illustrating the effects of irrigation diversions and drainage returns on the composition and concentration of the waters of the Rio Grande have been presented by Wilcox (16). Water quality data computed from analytical results given by Wilcox are shown in Table 7. These results cover the river reach from Santa Fe, New Mexico, to about 80 miles below El Paso, Texas. Irrigation projects are all along the river except in the Elephant Butte Reservoir section (San Marcial to Caballo Dam). The values given are weighted (according to flow) means of monthly composite samples for the year 1945. The dissolved solids data in Table 7 are of the same order of magnitude as the mean values given by Lowry (17) for the period 1931 to 1949 inclusive at Caballo Dam, El Paso and Fort Quitman. Referring to the data in Table 7, it is evident that as the total flow decreases due to consumptive use, the concentration of mineral matter increases, its composition changes; and the water becomes less satisfactory for further use, including irrigation, as it proceeds downstream.

Table 7 - Weighted Mean Concentrations of Water Samples, Rio Grande, 1945
(Sheet 1 of 2)

Downstream----------	Otowi (1) Bridge	San (2) Marcial	Elephant Butte(3)	Caballo Dam	Leasburg Dam	El Paso Texas	County Line(4)	Fort(5) Quitman
1. Total discharge (acre-ft)	1,131,550	813,750	839,690	882,920	814,170	568,900	280,620	207,710
2. Electrical conductivity (EC x 10^6 at 25°C.)	280	567	662	740	778	1210	2880	3200
3. Per cent sodium*	24	41	42	43	44	51	60	62
4. Boron (B) (ppm)	0.03	0.10	0.11	0.11	0.12	0.18	0.32	0.33
5. Dissolved solids (ppm)	190	380	430	480	510	802	1870	2060
6. Calcium (ppm as Ca^{++})	33.5	51.4	58.1	62.8	64.8	89.4	173	175
7. Magnesium (ppm as Mg^{++})	6.0	9.7	12.	13.1	13.7	18.8	36.0	44.6
8. Total hardness (ppm as $CaCO_3$)	108	168	194	210	218	300	579	620
9. Alkalinity(CO_3^{--} + HCO_3^-) (ppm as $CaCO_3$)	86	124	133	144	142	190	220	206
10. Carbonate hardness (ppm as $CaCO_3$)	86	124	133	144	142	190	220	206
11. Noncarbonate hardness (ppm as $CaCO_3$)	22	44	61	66	76	110	359	414

Table 7 (Continued)

(Sheet 2 of 2)

Downstream----------	Otowi (1) Bridge	San (2) Marcial	Elephant Butte(3)	Caballo Dam	Leasburg Dam	El Paso Texas	County Line(4)	Fort(5) Quitman
12. Sodium (ppm as Na^+)	16	52.9	63.5	73.6	78.9	146	407	461
13. Sulfate (ppm as SO_4^{--})	47	112	149	156	169	254	457	497
14. Chloride (ppm as Cl^-)	5	32	35	50	54	122	554	644
15. Nitrate (ppm as NO_3^-)	Trace	1	Trace	0.6	0.6	0.6	1	0.6

* Per cent sodium = $\frac{100\ Na}{Na + K + Ca + Mg}$ (Concentrations in equivalents per million).

(1) Near Santa Fe, New Mexico
(2) Upper end of Elephant Butte Reservoir
(3) Reservoir outlet
(4) Hudspeth County, Texas
(5) Approximately 80 miles below International Dam at El Paso.

In discussing southwestern water problems in 1938, Lippincott (18) summarized the quality changes in the Rio Grande as follows:

"The increase in salinity of the waters of the Rio Grande due to their use and re-use in its long drainage basin is of interest. The river rises in high granitic mountains in Colorado where the salinity of the water is low, amounting to 110 ppm (0.15 ton per acre-foot of water) at Del Norte, Colorado. Tributaries enter along its course. At the Colorado-New Mexico boundary line the salt content has increased to 206 ppm. After the water is used near Albuquerque and as it enters the Elephant Butte Reservoir, this salinity has increased to 427 ppm. At El Paso it has become 832 ppm, equal to 1.13 tons per acre-foot, and at the lower end of the El Paso Valley at Fort Quitman, it is 2,120 ppm, or 2.88 tons per acre-foot. This increase in salinity with the irrigation use of water in the upper basin of the Rio Grande is interesting when considered in connection with the prospective greater irrigation use of the Colorado River in its upper drainage basin."

At comparable stations, dissolved solids concentrations given by Lippincott (18) check closely with the values contained in Table 7 and the average values (1931-1949) given by Lowry (17).

In the Arkansas River Valley in Colorado, irrigation has reached a high state of development. Normal stream flows in the summer season are used entirely for irrigation. There are 23 major irrigation diversions between a point about 50 miles above Pueblo and the Colorado-Kansas line. Return flows in excess of 200,000 acre-feet annually reach the river channel between Pueblo and Holly. About 500,000 acres are irrigated annually in the Colorado portion of the Arkansas Basin (19).

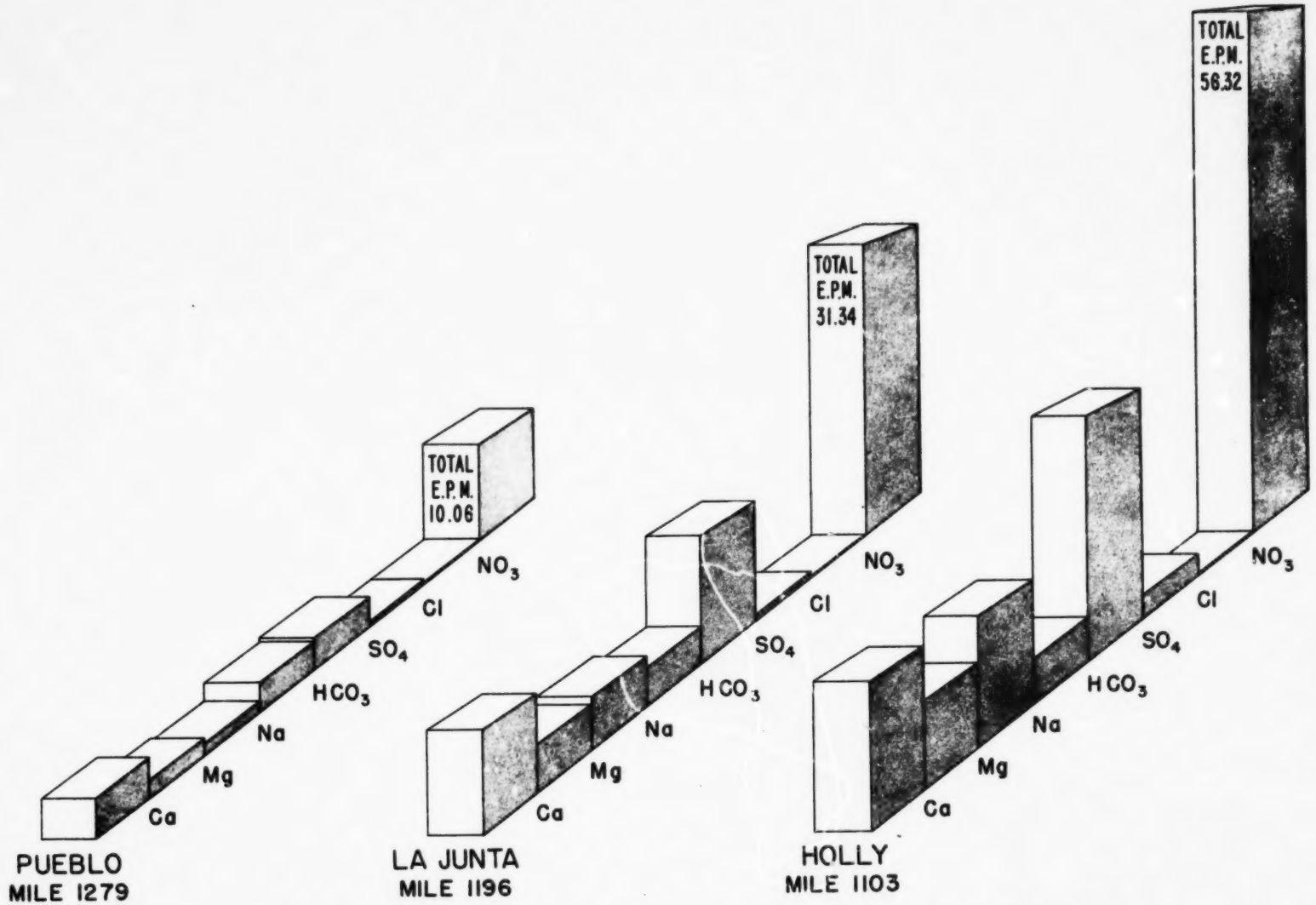
Percentage composition as well as concentration changes are illustrated by Bureau of Reclamation data on the Arkansas River between Pueblo and Holly, Colorado (20). Water quality data for the water year 1940-41 are presented in the following table and are shown graphically in Figure 1.

Table 8 - Arkansas River between Pueblo and Holly, Colorado

Mean quality of water - Arkansas River at 5 gaging stations, water year 1940-1941

	Pueblo		Nepesta		La Junta		Caddoa		Holly	
Approximate river miles from mouth	1279		1247		1196		1154		1103	
Discharge in acre-feet	503,200		567,800		107,600		309,900		169,000	
Total dissolved solids(ppm)	346		542		1088		1376		2034	
Per cent Na^+ (based on EPM of cations)	16		21		27		34		37	
Ion	EPM*	Per cent of total EPM	EPM*	Per cent of total EPM	EPM*	Per cent of total EPM	EPM*	Per cent of total EPM	EPM*	Per cent of total EPM
Ca^{++}	2.97	29.5	4.60	27.7	7.70	24.6	8.51	20.8	10.87	19.3
Mg^{++}	1.26	12.5	1.95	11.8	3.67	11.7	5.00	12.3	6.81	12.1
Na^+	0.80	8.0	1.75	10.5	4.30	13.7	6.88	16.8	10.48	18.6
HCO_3^-	2.25	22.4	2.71	16.3	3.40	10.8	3.20	7.9	3.98	7.0
SO_4^{--}	2.54	25.2	5.19	31.3	11.48	36.7	16.15	39.6	21.89	38.9
Cl^-	0.20	2.0	0.33	2.0	0.75	2.3	1.01	2.5	2.22	4.0
NO_3^-	0.04	0.4	0.07	0.4	0.04	0.2	0.03	0.1	0.07	0.1
Total	10.06	100.0	16.60	100.0	31.34	100.0	40.78	100.0	56.32	100.0

* Equivalents Per Million.



MEAN WATER QUALITY- ARKANSAS RIVER

WATER YEAR 1940–41

18-A

Headden's (12) analytical results on Arkansas River samples collected in 1898 and 1903 showed generally similar dissolved solids changes in the river reach, Canon City, Colorado, - Rocky Ford, Colorado. Canon City is roughly 50 miles upstream from Pueblo, and Rocky Ford about 70 miles below.

Discussion

Considerable variations in the effects of irrigation return flow on water quality are to be expected. Differences arise due to size of irrigated areas, number of times the water is used, properties of the soils, age of irrigation project, nature of the aquifers, rainfall, dilution, temperature, irrigation practices, storage reservoirs, etc. It is therefore very difficult to generalize, except in a rough qualitative way, about the effects of return flow on receiving water quality. However, some general trends may be predicted from consideration of what happens when irrigation water is applied to land. Little of the total mineral content of the water is taken up by the plants (8); consequently, as evaporation and transpiration occur, there is appreciable concentration of the salts. Most of the original mineral matter is now contained in a much smaller volume of return flow. Repeated salt concentration by evaporation and transpiration, plus leaching of arid soils which usually contain more soluble matter than soils in humid regions, can result in considerable mineral gain in receiving streams. The general tendency in a stream, as the water is used and re-used for irrigation, is in the direction of a significant increase in total dissolved mineral solids with attendant increments in hardness, chloride and sulfate content. The nitrate content may not increase to any great extent, probably because nitrate is in demand as a plant food.

It is evident that with the increase in salt concentration some important

changes in the percentage composition of the dissolved solids also occur. The trend will usually show a percentage decrease in calcium accompanied by an increase in sodium. Changes in the proportion of magnesium may not be as great. However, as in the case of the other ions, the actual concentration of magnesium will usually show a marked increase. On a percentage basis, bicarbonate will generally decrease but sulfate and chloride may increase substantially.

Reduction in the proportion of calcium in the dissolved mineral matter probably results from precipitation of calcium carbonate in the soil plus base exchange action by the soil. Loss of calcium by precipitation and base exchange results in a higher proportion of sodium in the dissolved mineral matter, an undesirable change from the standpoint of further irrigation use. Sodium, like calcium, will react with base exchange materials in the soil. If sodium is the predominant cation in an irrigation water, undesirable changes will take place in the soil, rendering it less permeable, difficult to work, and generally unsuited to crop production. (16) The adverse effects of high-sodium-content waters have been summarized in the saying "Hard water makes soft land and soft water makes hard land." (16)

In addition to its sodium content in relation to other cations (% Na), irrigation water quality is judged on the basis of total dissolved salts (or electrical conductivity) and boron content. (16) Dissolved solids of 1500 ppm and a boron content of 1 to 3 ppm are approximately the maximum concentrations that can be tolerated, and substantially lower concentrations are of course desirable.

Mineralized irrigation percolate has been termed "irrigation sewage" (21) and the problem of dealing with this residual salt load has been recognized as one of the phases of irrigation practice about which more information is

needed (8).

Irrigation agriculture may be thought of as a process industry in which water, as is generally the case in such industries, plays a major role. The water thus used may become so laden with the irrigation process salt wastes that it is no longer well suited for further irrigation or other beneficial use. Disposal of the burden of residual salts from irrigation projects in such a way that receiving water quality will not be unreasonably impaired is one of the many problems associated with multiple use of water resources. Probably there will be more concern with this problem in the future than there has been in the past. The country is growing steadily and the water quality as well as quantity needs of cities, farms and industries will have to receive increasingly careful study. The water works profession is not alone when it comes to interest in water quality. The irrigation farmers certainly have a real stake in the whole problem of water quality. Irrigation water quality requirements are just as exacting in some respects as those for public water supply or industrial use.

Dilution of a mineralized water with one of low mineral content is one means of maintaining reasonably satisfactory water quality. One way in which dilution water may be made available is by reduction in consumptive use. Consumptive use of water in irrigated areas is made up of water actually consumed by the growing crops plus incidental consumption. Consumptive use of water by the crops themselves cannot be decreased without decreasing crop yields (22) and the tendency is in the direction of higher crop yields per acre. Reduction of the water used by nonbeneficial vegetation probably presents one of the best opportunities for saving water. For example, salt cedars in the west are estimated to consume of the order of 20 billion gallons of water daily (4). Im-

proved efficiency in the conveyance and application of irrigation water also offers opportunity for saving water (22).

PHOSPHORUS, INSECTICIDES, HERBICIDES

Of the three major plant-food elements potassium, nitrogen and phosphorus, the latter is probably of most interest to those responsible for water works operation. Nitrogen, phosphorus, potassium and probably many other elements are important in connection with algal production. However, for many blue-green forms phosphorus seems to be the limiting key element in the fertilization of lakes and impounding reservoirs. Sawyer has indicated that potassium is normally in adequate supply and that deficiency in nitrogen can be overcome by fixation from the atmosphere (23) (24). Control of the amount of phosphorus entering lakes is a problem of increasing concern. Sawyer (23) (24) has suggested a limiting concentration of inorganic phosphorus, based on his observations at numerous Wisconsin lakes, of 0.01 ppm. This was believed to be the approximate level of phosphorus that could be tolerated in the Wisconsin lakes without supporting undesirable algal growths.

Major sources of phosphorus in surface waters are sewage and drainage from agricultural land.

Rudolfs' (25) studies of the quantity of phosphorus in sewage indicated phosphorus ranges of from about 0.5 to 1.2 lb. per capita per year. Sawyer (23) reported 1.2 lb. per capita per year at Madison, Wisconsin during a two-year survey (1942-44).

The phosphate content of sewage has been increasing in recent years with the increased use of detergents containing various phosphate compounds. The consumption of phosphates in the detergent and water softening field is now

about 2.5 times that of 1941. Total consumption of phosphates in the detergent and water-softening industry during 1950 was 535,000 tons, or about 6.7 pounds per capita per year. The average phosphorus content was about 23.4%, equivalent to 1.57 pounds of phosphorus per capita per year.

Sawyer (24) investigated the contributions of lake fertilizing matters from agricultural areas in connection with his Wisconsin lake studies. His results indicated that agricultural runoff plus seepage in the Madison, Wisconsin, area contributed approximately 255 pounds of phosphorus per square mile of drainage area per year. Biologically treated sewage was found to supply approximately 1.2 lb. of phosphorus per capita per year. Sawyer concluded that on a phosphorus basis the population equivalent of drainage from one square mile of agricultural land is equivalent to 212 persons.

Probably an average figure of 255 pounds of phosphorus per year per square mile of drainage area is high for irrigated western land where rainfall and runoff are low. For any great quantity of phosphate to appear in irrigation return waters, the phosphate would have to escape fixation by the growing crops and precipitation in the soil. Nitrates do not appear to be a serious problem in streams receiving irrigation drainage, and probably wasteful quantities of phosphate fertilizer would have to be applied to irrigated land in order to contribute major quantities of phosphate to surface waters. However, more data are needed on the phosphate content of irrigation return waters before a definite answer can be given. It seems fairly certain though that whatever the phosphorus problem is or may become, this problem is not limited to irrigated areas. Fertilizer and detergent sales are on the increase all over the country. Sewage and runoff from unirrigated land have already been shown to be important sources of "available" phosphorus.

Somewhat similar statements apply to the possible adverse effects of insecticides and herbicides on water quality. Whatever problems may exist now or in the future are not necessarily associated with irrigation. It seems probable that insecticide problems are more likely to be encountered in humid areas. The greatest water pollution danger would probably exist when a high-intensity, short-duration rainfall occurs just after heavy application of an insecticide. One experience recently reported (26) indicates that a combination of rainfall and repeated applications of various insecticides including "toxaphene" resulted in sufficient toxic material being washed into the streams to cause major fish kills. There was concern over the safety of public water supplies involved but apparently the low solubility of the insecticides used plus water treatment was sufficient to insure safety. Data on the fate of insecticides and herbicides in soil and water under a variety of conditions are needed.

Herbicides are employed for the control of weed growth in and along irrigation canals. Considerable research is in progress on herbicides and their use (3). According to Flaigg (3) no ill effects on water quality have been encountered in connection with the Bureau of Reclamation's operations involving the use of herbicides for canal weed control or destruction of salt cedars. Flaigg (3) indicates that there is some evidence that 2,4-D is destroyed in moist soil by bacterial action and also that it may be immobilized in the soil by adsorption or by the formation of a relatively insoluble calcium salt. Possible difficulties associated with the use of 2,4-D and other weed-killers have been cited by Goudey (27) and Surber (28).

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